WEATHER AND FOREST INFLAMMABILITY IN THE SOUTHERN APPALACHIANS [1]

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FOREST FUELS AND THE FIRE SEASONS

The Appalachian forest, composed largely of deciduous species, creates a fire hazard over its entire area through the annual fall of leaves. Even the pines, and to a lesser extent the other coniferous species, add each year to the amount of litter upon the ground.

The seasons of inflammability are generally limited to the spring and fall, when there is neither a cover of snow to check the drying of the forest floor nor a protective cover of green vegetation. Fires occur but are not prevalent during the winter season, and are rare in the summer, but sometimes occur in exceptionally dry seasons. During the spring and fall the leaf litter is exposed to rapid drying through the effects of sunshine, dry atmosphere, and winds.

The presence of a quantity of litter on the ground is the primary requisite for a fire hazard, and this is most pronounced in the fall when the new crop is all down and has not yet become settled or compacted through the beating action of rains and snow. In the spring this crop of leaves is more compacted, but has not decayed enough to reduce appreciably the total amount of inflammable material. During the summer disintegration goes on rapidly, and by the succeeding fall the hazard is much reduced until the new crop is down.

Grass and other annual or biennial vegetation is most important on forest land recently cut over or partially stocked. Similarly, hardwood slash is not a primary hazard but serves to intensify the heat of fires carried largely by other fuels. Both of these conditions are very subordinate in point of area to the leaf-litter hazard.

Leaf litter is extremely sensitive to changes in atmospheric moisture; in fact, it may be dampened to a condition of low hazard without rain through the action of dew and frost in times of high humidity. In rare periods fire will run briskly through the night, but normally day is the time of hazard.

STORM MOVEMENT

Fire hazard is directly associated with the weather, and has a definite place in the usual cycle of storms. In this region it is associated with the weather of the anticyclone. The region is so situated that a wave of low pressure can scarcely pass across the continent without bringing at some time a period of southerly or easterly winds to the region. These, coming from the direction of the Gulf of Mexico or the Atlantic, tend to increase the atmospheric moisture. The period of highest hazard is that of low relative humidity, and is limited to times of continental winds from the west and northwest, or periods of calm when air pressure is high over the Appalachian region.

There comes regularly in the cycle of storms a change of wind from the south and east to winds from the west and northwest, as the LOW center passes to the east, and the masses of polar air advance behind it. The character of this wind shift will, of course, be determined by the path of the storm, whether to the north or south of the region in question.

The fact of importance from the fire standpoint is that after each storm the wind shifts from its ocean and Gulf sources to a continental source. This shift brings colder air that is not only dry from its source, but becomes drier as it warms on its southerly course and as it settles to lower elevations. With the shift of wind come higher air pressure, lower temperature, and lower absolute moisture content of the air. It is a time of fair weather.

The series of conditions which follow the passage of a storm are clearly discernible from the records of the Weather Bureau taken each day and mapped for the central part of the continent. For the Appalachian region, changes coming from the west in the condition of the weather can in a general way usually be foreseen for a period of three days, and from the southwest for a period of at least 36 hours. Within these limits forecast of dry periods can be made more certainly than for storms, and adjustments may be made in the disposition of the forest protective forces. Well organized forest protection forces can utilize the regular forecasts of the Weather Bureau, which are approximately for a 36-hour period. Beyond this, a knowledge of the usual sequence of the weather gained through visits to a station where daily maps are available will make possible forecasts for even longer periods. Proficiency in making such forecasts beyond the usual 36-hour period will depend upon familiarity with the usual courses of the storms as they cross the continent, with their rate of travel, and the influence of the cyclonic disturbance on precipitation, atmospheric moisture, wind, and temperature. Much more than the mere prospects of precipitation can be learned from the study of the daily weather map.

Changes in temperature, wind, and humidity are likewise important and can be forecast to some extent.

Figure 1 illustrates the correlation between the several factors of weather and the occurrence of fire, and clearly indicates the weather which attends a period of inflammability. This is the graphic representation of the conditions during the fall fire season of 1922, including current fires, which are shown by dots on graph 4.

Rains (graph 2) occurred at times of low air pressure (graph 5). With the increase in air pressure there occurs a drop in vapor pressure (graph 4). This is the significant cause of the increase in inflammability which followed. Low vapor pressure (low absolute humidity) succeeds each storm in this region when the wind shifts from south and east to a westerly or northwesterly direction. Dry weather ensues until relieved by another storm. Dryness of the air is expressed both by the graph of a relative humidity (graph 1) and by the saturation deficit shown in graph 3. In the latter instance the width of the black zone indicates the capacity of the air for further absorption of water. The leaf fall, which began in the latter part of October, increased the hazard as shown on graph 4 by the prevalence of fires.

The rate of evaporation is conditioned upon three factors, temperature, humidity, and air motion. All three of these have a very definite relation to the move-

[1] The study of forest-fire weather in the Southern Appalachian region has been carried on by the Appalachian Forest Experiment Station at intervals since the fall of 1922. During this time two general phases of the subject have received attention—the relation of current weather conditions to forest-fire occurrence, and the rate of drying forest fuels under different conditions of weather. Two papers have been published on the first phase of this subject:
Forest Fire Weather in the Southern Appalachians. MONTHLY WEATHER REVIEW, April, 1923, 51: 182-185.
Forest Fires and Storm Movement. MONTHLY WEATHER REVIEW, May, 1924, 52: 257-259.
The present report presents in condensed form results of studies of the rate of drying of forest fuels made during the fall season of 1925 and the spring of 1926.

ment of storms, and none of them can be considered alone as the cause of forest dryness. Temperature has a direct effect upon the relative humidity, and the air motion also affects the humidity by the constant removal of the humid air from contact with the surface of the leaf litter. Of the three, temperature is the least important by itself, but the fact must not be disregarded that low relative humidity rarely occurs with low temperature during the fire season. These facts are cited because they bear on the analysis of the results obtained from the study of the rate of drying of litter.

If storms pass south of the Appalachian region, heavy precipitation usually occurs, lasting until the center has

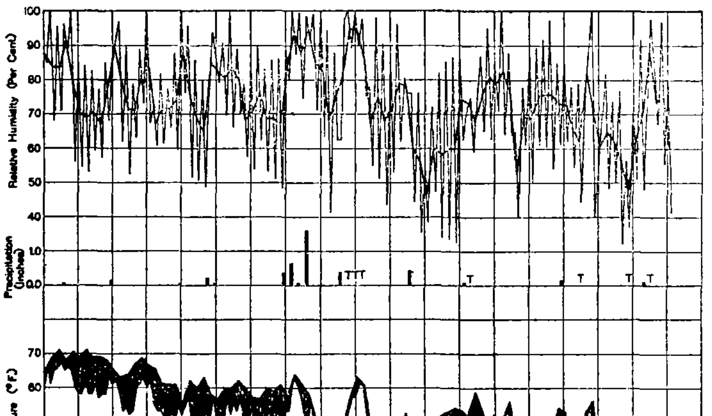

FIG. 1.—March of certain weather elements at the Appalachian Forest Experiment Station during September, October, and November, 1922

moved out into the North Atlantic. But if the storm passes up the Ohio Valley, though it usually brings rain to the Appalachian region, it may fail to do so. A storm passing over or adjacent to the Great Lakes region, without bringing precipitation to the Appalachians, increases the wind velocity and otherwise increases the fire hazard in the latter region both during and after its passage.

The foregoing discussion is intended to show that the periods of greatest inflammability in this region occur after the passage of a storm, and while the region is under the influence of the following anticyclone. Obviously the drying of the litter will lag behind the change to drier air. To determine the extent of this lag, tests of the drying rate were made during the fall fire season of 1925, and the spring season of 1926.

THE FALL FIRE SEASON, 1925

Meteorological records were kept from the 1st of October to the 24th of November on opposing north and south slopes on the Bent Creek experimental area of the Pisgah National Forest. In addition to these temperature, humidity, and rainfall records, samples of litter were tested for moisture content.

Weather conditions and leaf fall.—The season was generally unfavorable to fire. While the late summer and early fall were very dry, heavy rains just before the beginning of the leaf fall caused an apparent resumption of vegetative activity by the trees, so that they were in the main able to retain their leaves after the first heavy frost of October 10. The walnut, locust, and poplar were defoliated through the action of this early frost, but the bulk of the forest lost its leaves slowly. Even the rains of the first few days of November failed to bring down the leaf crop, although it had been subjected to repeated freezing during the last part of October. The rain of November 7 did cause the bulk of the leaves to fall, with the exception of those of the more resistant oaks, which, however, were practically all shed after the heavy rain of November 11. This extremely late leaf fall was quite as significant a factor in producing a safe fire season as was the prevalence of rain and high humidity. The late leaf fall alone would have delayed the fire season at least two weeks beyond the usual time.

Insolation.—The sun rises on the southerly exposures several hours before it begins to make a visible impression on the thawing of true north exposures. In fact, on some of the steeper north exposures, owing to the depression of the sun in the fall fire season, its rays must pass through a great extent of tree crowns at a very flat angle, and a few conifers in the forest will practically obstruct it for the entire day. This was observed to be the chief factor in creating a difference in the drying rate between the north and south exposures. On windy days the effect was less noticeable than on still mornings, when a heavy dew or frost was quickly dissipated by the sun on the south sides of the ridges but lingered until 10 a. m. or later on the north sides.

Character of litter and reaction to drying.—When the leaves first fell, they contained considerable sap and did not dry as readily as they did later. Resaturation of the litter under favorable conditions of moisture occurred very quickly, so that a relatively small amount of precipitation made the leaves noninflammable. Even a heavy dew caused the litter to become quite flexible, and the heavier rains during the test were little more effective in wetting the litter, except that the saturation of the soil increased the humidity of the air at the surface during the nights following the storm and caused reabsorption of water by the litter.

With the beginning of rain, hardwood litter absorbed water in excess of its dry weight in a comparatively few minutes, and gave up this water in the course of a few hours of dry weather down to a 40 per cent moisture content. The drying continued more slowly beyond this point, and the relatively fresh condition of the litter during the fall season checked the drying observed at about 8 per cent. Drying to below 10 per cent occurred only under very dry weather conditions.

All hardwood leaves showed a tendency to curl, creating air spaces in the litter. For this reason the wind was able to exert a more pronounced influence than it could had the litter been more compact. When the wind reached medium velocities, leaves drifted about the woods a great deal in spite of the heavy and frequent rains. Leaves on the south slope are deeper cut, both because of the site upon which they grow, and by reason of species; they also dry more rapidly than those of the north slope. For these reasons they curl up more and are blown about more than on a moister site.

An analysis of the weather during the period covered by this study (fig. 2) shows that the combined effects of late fall of leaves, frequent rains, and high humidities made this an unusually safe season. One of the most severe periods occurred after the rain of November 12, when 2.21 inches of rain fell during approximately 24 hours. The rain ceased about 4 p. m. on November 12. Relative humidity fell rapidly during the night, reaching

FIG. 2—RECORD OF RELATIVE HUMIDITY AND RAINFALL AT STATION ON SOUTH EXPOSURE—BENT CREEK—1925

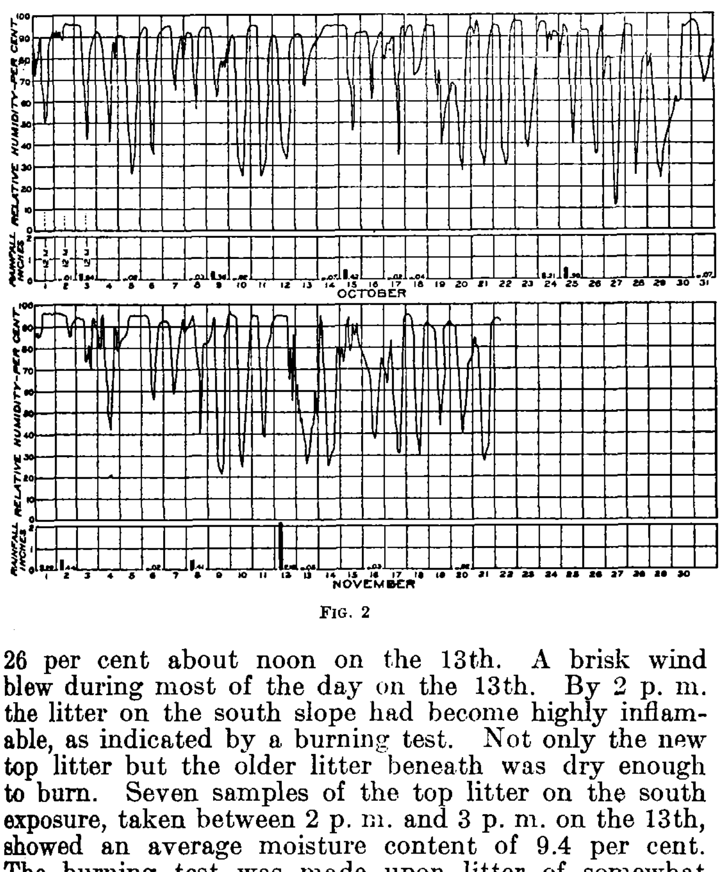

FIG. 2

26 per cent about noon on the 13th. A brisk wind blew during most of the day on the 13th. By 2 p. m. the litter on the south slope had become highly inflammable, as indicated by a burning test. Not only the new top litter but the older litter beneath was dry enough to burn. Seven samples of the top litter on the south exposure, taken between 2 p. m. and 3 p. m. on the 13th, showed an average moisture content of 9.4 per cent. The burning test was made upon litter of somewhat higher moisture content than this. Five litter samples taken at 11.30 a. m. on the following day (November 14) showed an average moisture content of the top litter on the south exposure of 16 per cent. This increase over the moisture percentage of the afternoon before was due entirely to the increase in humidity and the precipitation of dew on the night of the 13th. By midafternoon the average moisture content of the new litter was 10.8 per cent. Litter on the north exposure reached a moisture content of 18 per cent on the 14th and would have burned readily.

A second, less severe, period of drying occurred on November 17, 18, and 19. On the second day the average new litter on the south exposure dried out to about 10.8 per cent as in the previous case, though the top leaves which were in the sun reached a lower percentage than this. High night humidities and absence of wind made the drying slower than in the previous instance and reduced the night hazard to a very low level. These two periods were the driest that occurred between October 1 and November 24, after the fall of the leaf crop.

Physical determination of moisture content of litter.—In order to provide a field method for the determination of moisture content of the litter, about 50 determinations were made by weighing and correlated with series of breaking tests. While the heavier leaves, such as those of the post oak, crack or break with higher moisture content than the thinner leaves, such as white oak, the amount of this variation is not great. The following relations express the average results of these tests:

Leaves having 20 to 40 per cent moisture crack if creased, but do not break entirely.

With from 14 to 20 per cent moisture they crack if folded more than a right angle.

At an average of 14 per cent moisture they crack when bent at a right angle, but do not break freely, especially in the veins.

At an average of 10 per cent moisture they break entirely apart if bent at a right angle. Litter at 10 per cent moisture breaks up if crushed in the hand, but does not crumble into small pieces.

Freshly fallen leaves are tougher at any given moisture content than those which have been dried and saturated again.

EARLY SPRING CONDITIONS, 1926

Determinations of the moisture content of the leaf litter were made during three days (March 25–27) to get a more definite expression of the drying rate. Percentage of moisture was computed, as before, on the basis of the oven-dry weight. The leaf litter had been subjected to packing by snow and rain during the winter, so that very little of it was loose enough to blow about in winds of medium velocity. Repeated saturation, freezing in saturated condition, and drying had occurred also during the winter. The effect of compacting was to reduce the influence of the wind on the rate of drying in the spring, while at the same time the weathering of the litter probably caused it to dry more rapidly.

Samples of litter were collected during the day at intervals of 15 to 30 minutes, percentages of moisture were determined and these were used as the basis of an average curve of drying. Table 1 shows the results read from these curves.

TABLE 1.—*Percentages of moisture in litter* [1]

Hour	Mar. 24	Mar. 25	Mar. 26	Mar. 27	Mar. 28
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
8 a. m.		28.0	137.0	54.5	
9 a. m.		18.5	129.0	49.0	
10 a. m.		14.5	120.0	44.0	
11 a. m.		12.0	110.0	38.0	
12 m.		10.0	99.0	32.0	
1 p. m.		9.0	86.0	25.5	
2 p. m.		8.0	72.0	18.5	
3 p. m.		7.5	52.0	12.0	5.7
4 p. m.		7.0	25.0	5.0	
5 p. m.	6.0	13.0			
Number of samples	2	26	18	30	5

[1] Values read from an average curve.

Percentage of moisture in litter computed in all cases on the basis of oven-dry weight.

Two samples collected at 5.15 on March 24 showed an average of 6 per cent moisture, the result of two days' drying with light to medium winds, clear weather and relative humidity generally below 50 per cent. By 8 a. m. March 25 the wind had shifted to the south and vapor pressure was rising, but due to a considerable rise in temperature during the day the relative humidity ranged between 52 per cent and 38 per cent. A light rain started just before 5 p. m., continuing at intervals during the night. A fall of 0.24 inch of rain was recorded by the gauge at the place of the tests. This was enough to wet the top leaves, but not enough to wet the litter throughout.

The first determinations made on March 26 showed a moisture content of 137 per cent of the oven-dry weight. During the day, which was cloudy with a temperature below 50 degrees and a humidity above 50 per cent, the litter dried down to about 25 per cent. During the night of March 26, the relative humidity ranged from 70 per cent to 90 per cent, and the litter absorbed moisture up to 54.5 per cent at 8 a. m., March 27. This day was moderately dry with fluctuating light winds, and relative humidity remaining above 40 per cent. The litter dried out to about 5 per cent by 4 p. m., when the falling temperature caused the relative humidity to advance sharply. Freezing temperature developed during the night. Five determinations made on March 28 at 3 p. m. agreed within 2 per cent and averaged 5.7 per cent moisture content. At this time relative humidity was 19 per cent and vapor pressure 0.069 inch.

The period of these tests was not exceedingly dry except at its close. High night humidities, the absence of brisk winds, and comparatively low temperature were all unfavorable to rapid drying. Still on four days out of five the top litter had dried to 7 per cent or lower, and even on March 26 fire would have burned between the hours of 3 and 4 p. m. This series of tests tends to verify that of the fall of 1925, the conclusion being that one day of sunshine with even medium winds and humidity at or below 50 per cent creates a fire hazard. Temperature is chiefly important because of its influence upon relative humidity.

SUMMARY

After the fall of the new litter a fire hazard can be created through the agency of sun, wind, and low relative humidity on south exposures in a single day following a heavy precipitation.

On north exposures during the fall season, due to the small angle of insolation and shade cast even by hardwood crowns, no material hazard can be created in one day.

Wind is necessary for rapid drying, especially on north exposures.

Leaves absorb more than their dry weight of water and absorb moisture from moist air without the agency of rain, dew, or frost. The moisture content of litter is thus affected by night humidities.

The period of active drying during the fall season o 1925 was limited to 6 or 7 hours during midday even on the more hazardous days. High relative humidity was common throughout all nights after the leaf crop came down.

Low moisture content can be estimated by a breaking test.

The conclusions from the fall season of 1925, as regards drying rate on south slopes, were generally verified in the spring season, although lower moisture percentages were found.

Conditions of wind, sunshine, and relative humidity favorable to forest fire are the regular aftermath of the passage of a storm, and can be forecast with more certainty than precipitation.

Unusual hazard is caused by continuation of high pressure over or west of the Appalachian region, or by the passing of a storm without precipitation in the region.

LIGHTNING STORMS AND FOREST FIRES IN THE STATE OF WASHINGTON

By GEORGE W. ALEXANDER

[Fire-Weather Warning Service, Seattle, Wash., March 4, 1927]

The lightning storm, usually called the thunderstorm, might appear to be a somewhat unimportant climatic factor in the Pacific Northwest to one basing an opinion on published compilations of thunderstorm frequency. Isoceraunics based on reports from Weather Bureau stations for the 20-year period 1904–1923 (*1*) indicate an annual frequency of 5 storms or less for the coastal regions of Washington and 10 or less for the rest of the State, except the extreme southeastern corner. For the period of record at the different stations, varying from 35 to 45 years, the annual averages of number of storms reported are: For Seattle, 5; for Walla Walla, 7; and for Spokane, 8. The reported frequency for the entire Pacific coast is similar, except that an annual average of 15 storms is ascribed to eastern Oregon, to Idaho, and to western Montana.

On the other hand, reports of the number of lightning-caused fires on the national forests and on State and privately owned timberlands in the coast States show that such storms are of extreme importance. For the season of 1926 the grand total of lightning fires was 3,520, or 36 per cent of all the fires reported in California, Oregon, Washington, Idaho, western Montana, and British Columbia. Of these, 2,468 were on the national forests (51 per cent of all fires on the forests). For the 1926 season in the State of Washington there were 192 lightning fires on the national forests and 126 on private and State lands, being 48 and 11 per cent, respectively, of the total number of fires; and the damage caused, especially in eastern Washington, was even greater, in proportion to the total damage from fires, than the numerical percentage would indicate. For the season of 1925 the lightning fires on the national forests numbered 253 (54 per cent of the total) and on other lands 155 (13 per cent); the records for preceding years show similar numbers and percentages.

These figures indicate, especially to one studying the effect of weather on fire hazard, that, far from being negligible or incidental, lightning must be considered as of major importance, particularly in the mountainous regions in which is located most of the national forest area, and that fire-weather warnings which do not localize to the greatest possible extent the imminence of lightning storms fail in a large measure to achieve their purpose.

Realizing the need for complete data on the occurrence of lightning storms for purposes of both record and research, the Forest Service in 1924 furnished their mountain lookouts with forms on which to record the date, hours of beginning and ending, direction of movement, amount of accompanying precipitation, and other